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MARINE INDUSTRY STANDARDS  
WELDING  
INDUSTRIAL ENGINEERING  
EDUCATION AND TRAINING

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## **1995 Ship Production Symposium**

### **Paper No. 28: A Production Control System Based on Earned Value Con- cepts**

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# 1995 SHIP PRODUCTION SYMPOSIUM

## Commercial Competitiveness for Small and Large North American Shipyards

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# A Production Control System Based on Earned Value Concepts

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## ABSTRACT

In the last four years, Astilleros Espanoles S.A (AES) has completed the implementation of its Shipbuilding Industrial Model based on the use of a Product Work Breakdown Structure for each new construction shipyard. As a logical development of this model, a new Production Control System has been built using Earned Value Techniques. This article describes the state of the implementation of this production control system.

First, the basic structures of the Shipbuilding Model are defined as:

- Product Work Breakdown Structure of each Ship under construction
- Process Breakdown Structure of the Shipyard and : Organizational Breakdown Structure.

Also described is how these structures are reflected in the basic logical concepts of the Production Control System product, process, organization, control accounts and control points, (by product processor organization), work packages and work orders.

The functional description of the Production Control System is explained. Some examples of outputs are presented stressing the method of result analysis prepared for each responsibility level of the shipyard, general manager, production manager, shop and production unit managers.

Next, the development of the implementation phase in one test corporate shipyard is described, as well as the main problems found and the way in which they have been solved.

Finally, some conclusions about the Production Control System are presented, together with several future planned developments for the system.

## NOMENCLATURE

ACWP	Actual Cost of Work Performed
AESA	Astilleros Espanoles S. A
BAC	Budget at Completion
BCWP	Budgeted Cost of Work Performed
BCWS	Budgeted Cost of Work Scheduled
CCA	Cost Control Account
CPI	Cost Performance Index
CSC	Cost Schedule and Control System

## EAC

IEAC  
NSRP

## OBS

## PAM

## PBS

## PIMET

## POAM

## PWBS

## TCPI

## WO

## WP

Estimate at Completion

Independent Estimate at Completion

National Shipbuilding Research Program

Organizational Breakdown Structure

Process Assignment Matrix

Process Breakdown Structure

Plan Integral de Mejoras en Tecnologia (Integrated Technology Improvement Plan)

Product Assignment Matrix

Product work Breakdown Structure

To complete Performance Index

work order

Work Package

## INTRODUCTION

In the last four years, an important effort has been completed design, develop and implement a Shipbuilding Industrial Model, based on the use of zone and stage prediction technology, flexible production planning and scheduling, and product oriented breakdown Structure. As a necessary development for this industrial model, a specific project was started with the target to design and implement a new Production Control System, based on the application of these related techniques and the use of Earned Value concepts.

For this purpose, a specific team was created, which assumes as its basic target the modification of the conventional 'Activity' concept to the new 'Product' concept

This team connection with the factory production team, developed a new production organization process, based on the use of interim products as planning and scheduling units. Each Interim Product takes the place of an old activity planning element and introduces a new relationship between the three basic elements related to the production frame

- Product as the element to be done,
- Process, as the way to produce using Group Technology rules, and
- Organization, as a specific group in charge of getting the product finished.

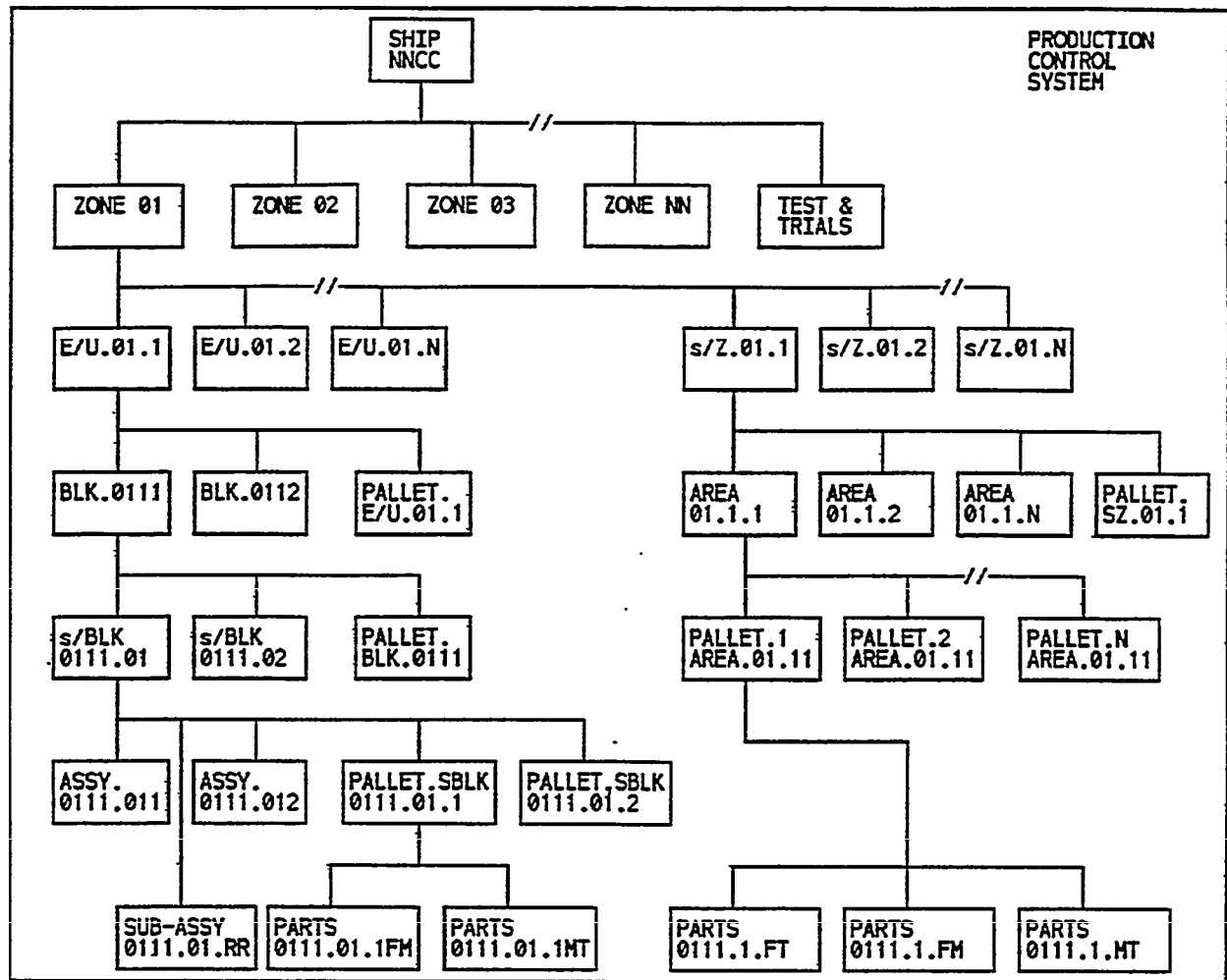


Figure 1.A sample Product Work Breakdown Structure

The second basic concept, Earned value, introduces a complementary innovation on the conventional production control, in the fact that the production progress is measured by the individual progress of each product scheduled. Earned value concepts and methods are not described, since they are well known and enough bibliography exists on them. What is shown is their practical application to new construction control in shipbuilding

The use of Group Technology concepts, allows, besides a better industrial production performance, a more accurate estimation of future results, based on actual performances for each considered group. The relationship between product process and production units (Organization) has been established under the rules of Group Technology.

The new Production Control System changes the old concept of 'results measurement' to the new 'production Management', providing continuous information on cost and schedule variations on each product, at each product level considered, and a complete analysis of production performance and productivity parameters.

This project is included in a larger Productivity and Competitiveness Improvement project which has its origin in the PIMET project (Plan Integral de Mejoras en Tecnologia or Integrated Technology improvement Plan), performed along the last five years, using some ideas the National Shipbuilding Research Programme (NSRP) programmes and documentation.

## THE PRODUCT ORIENTED WORK BREAKDOWN STRUCTURE

It is not considered necessary to redefine the Interim Product concept that has been very well established in the NSRP papers. In this paper only will be described the way this concept has been taken and applied to commercial shipbuilding, like a sophisticated oil carrier.

In the beginning of the project a Product oriented Work Breakdown Structure (PWBS) was developed for a shuttle oil carrier, that was being built in the test ship. Each finished element was defined as a 'product' integrating steel and outfitting works, whose integration with other

products, or elemental components, produces a new and more complex product Figure 1 shows this basic concept which is applicable to any other ship.

Following this, any product at any level can be identified, and each of these products can be taken as 'control point' selecting the most convenient level in accordance to production control needs.

## THE PROCESS BREAKDOWN STRUCTURE

The following step was the production process identification and definition. Process is defined as the way to produce a specific product or element applying Group Technology concepts. Each shipyard has its own Process Flow, and its own Process definition

This process structure defines the Shipyard Production Structure through the identification of their Production Processes, all characterized by Group Technology concepts.

The main characteristics considered in the process definition are that it be:

Group Technology based,  
Clearly identified and  
Stable in efficiency parameters.

Under these concepts, the Process Breakdown Structure (PBS) of each shipyard has been developed, taking into account the functional differences, and the specificity of each of them. Figure 2 describes the basic scheme of these breakdown structures.

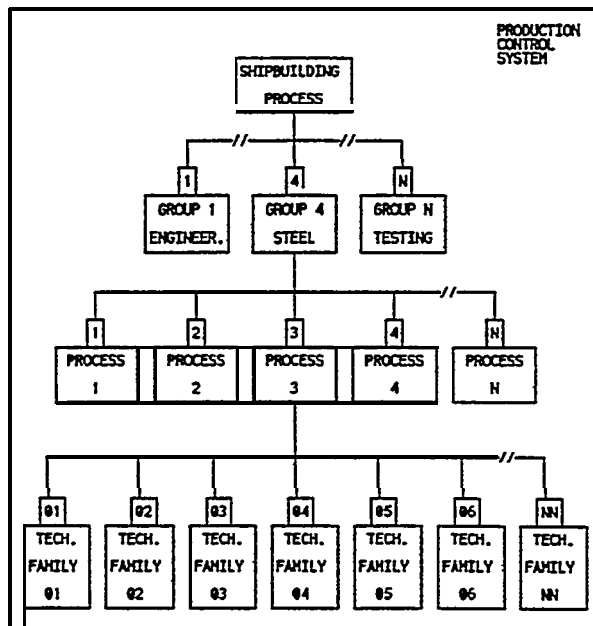


Figure 2. A sample of Process Breakdown Structure

As an example of a third level definition Technological Family, Table I shows the considered Technological Family

of the steel processes in the test shipyard.

A very-simple numerical codification system has been used to easily identify processes. In general terms, to produce a specific product it is necessary to perform tasks belonging to several processes.

Each process is assigned one or several units directly related to the amount of work required to carry out the task. For instance, the numbers of thin and thick pipes are considered reasonable units for the estimation of work for an outfitting job (e.g. welding pipes of welding thicknesses), that has been defined as a process at a certain level.

## THE ORGANIZATIONAL BREAKDOWN STRUCTURE

The Organizational Breakdown Structure (OBS) describes the structural organization of each Factory, and shows the different responsibility levels. This is a typical OBS, and in general terms is the same for all corporate shipyards. Figure 3 shows a typical OBS of a shipyard.

In this structure Production Unit is defined as a workshop or a workshop part, with facilities and utilities especially arranged for one or more technological processes, with Professionally trained Workers, and with their own process specifications, production procedures, dimensional accuracy systems, quality procedures and controls.

Each production unit is specialized in one or more processes, and produces one or more types of interim Products, under the most convenient production conditions, and with the best production performances. It is also possible for similar products to be made in two or more production units, with equal or similar processes, but normally the production performances are not equal.

## THE PROCESS ASSIGNMENT MATRIX

Crossing two basic structures, the Process Breakdown and the Organizational Breakdown Structures, a Process Assignment Matrix is obtained defining for each production unit the processes that the unit performs. Another layer of the matrix defines production performances expected of each production unit and specific process.

To estimate the required manhours for a given task two steps are followed. First, the quantities of the chosen units are determined. Second, an expected efficiency for each unit of measurement at the production unit is applied. This efficiency is taken from previous experience of the Yard, taking into account the procedural modifications to be made in each particular case.

This matrix enables one to plan the most convenient way to produce interim products or elements for each project in accordance with the work charge of the different workshops. Also provides an easy procedure to determine the differential costs derived from changes in the work assignments.

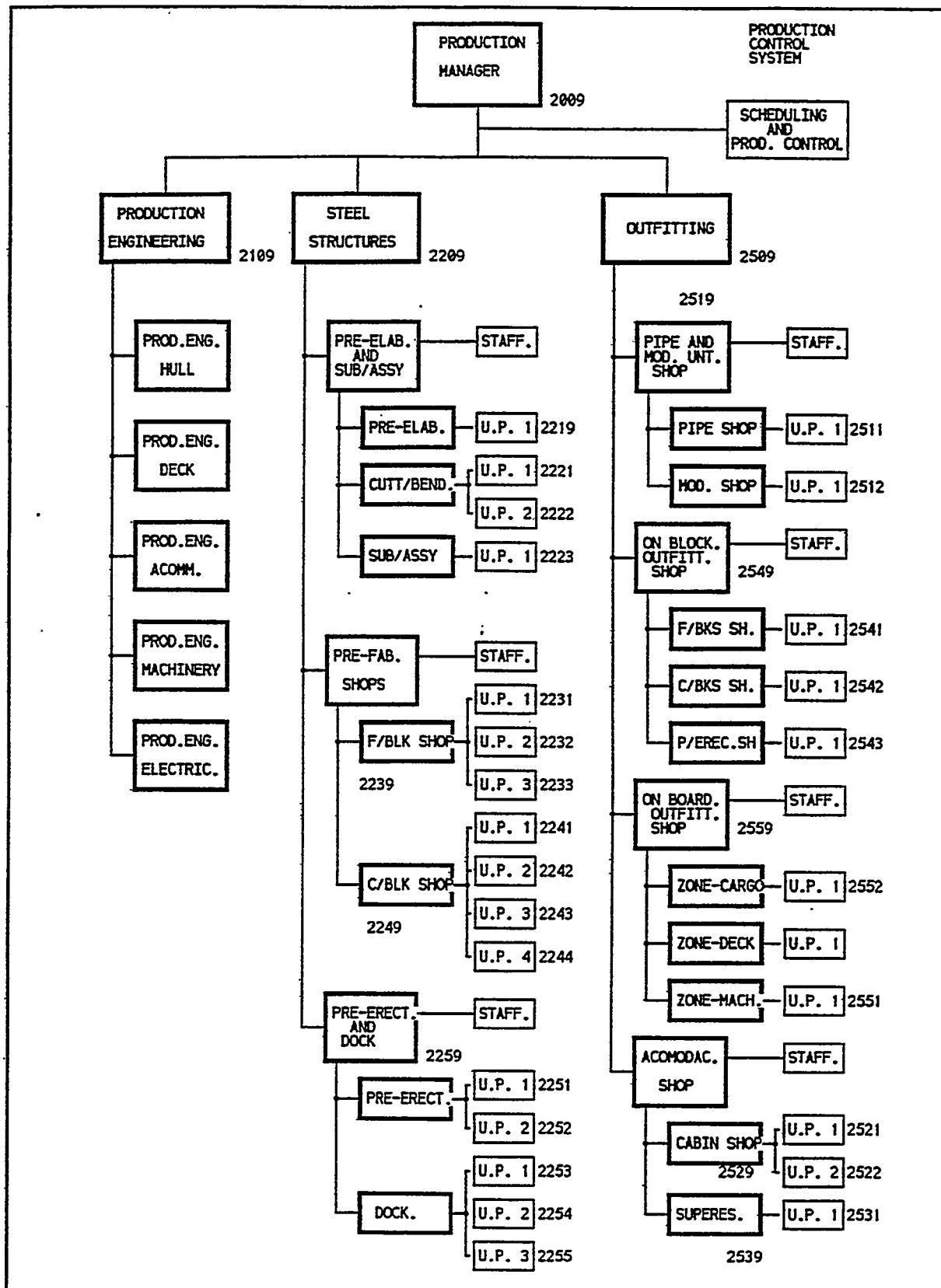


Figure 3. A sample of Organizational Breakdown Structure



TECHNOLOGICAL FAMILIES, PROCESSES AND GROUP IDENTIFICATION							
GROUP	PROC.	TECH. FAMILY	DESCRIPTION	UNIT 1	UNIT 2	PARAM. 1	PARAM. 2
4			Steel				
	4.1		Pre-elaboration				
		4.1.01	Sheet Pre-elaboration	Ton(gross)		Hrs/ton	
		4.1.02	Shape Pre-elaboration	Ton(gross)		Hrs/ton	
	4.2		Cutting				
		4.2.01	Sheet cutting for sub-assembly	Ton (net)	m.	Hrs/ton	Hrs/m.
		4.2.02	Sheet cutting for assemblies	Ton (net)	m.	Hrs/ton	Hrs/m.
		4.2.03	Shape cutting for sub-assembly	Ton (net)	# parts	Hrs/ton	Hrs/part
		4.2.04	Shape cutting for flat panels	Ton (net)	# parts	Hrs/ton	Hrs/part
		4.2.05	Shape cut & bending	Ton (net)	# parts	Hrs/ton	Hrs/part
	4.3		Bending				
		4.3.01	Sheet bending (simple)	Ton (net)	# parts	Hrs/ton	Hrs/part
		4.3.02	Sheet bending (normal)	Ton (net)	# parts	Hrs/ton	Hrs/part
		4.3.03	Sheet bending (complex)	Ton (net)	# parts	Hrs/ton	Hrs/part
	4.4		Sub/sub assembly production				
		4.4.01	Automatic sub/sub assembly line	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.4.02	Sub/sub assembly line	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
	4.5		Panel fabrication				
		4.5.01	Flat panel assembly	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.5.02	Shape inserts.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.5.03	Curved panel assembly	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
	4.6		Subassembly fabrication				
		4.6.01	Flat subassembly line	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.6.02	Curved subassembly line	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.6.03	Special subassembly line	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.6.04	P/p subassembly line	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
	4.7		Sub block prefabrication				
		4.7.01	Simple flat sub block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.7.02	Normal flat sub block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.7.03	Complex flat sub block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.7.04	Simple curved sub block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.7.05	Normal curved sub block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.7.06	Complex curv. sub block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.7.07	Special curved sub block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
	4.8		Sub block prefabrication				
		4.8.01	Simple flat block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.8.02	Normal flat block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.8.03	Complex flat block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.8.04	Simple curved block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.8.05	Normal curved block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.8.06	Complex curved block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.8.07	Special curved block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.
		4.8.08	Superstructure block prefab.	Ton (net)	Weld. m.	Hrs/ton	Hrs/m.

Table I. A sample of technological families and measurement units for steel manufacturing processes

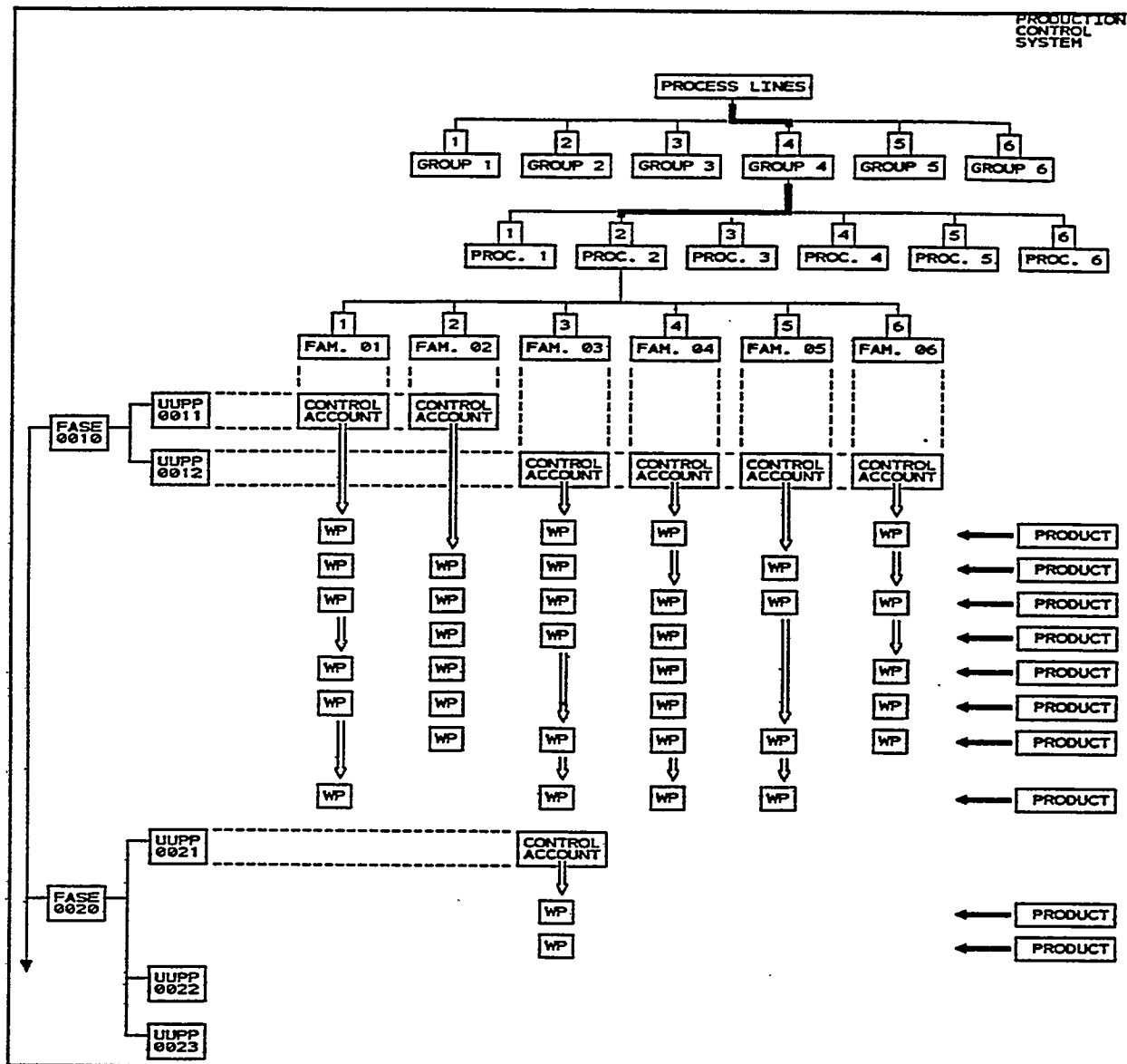


Figure 4. A sample of a Product Assignment Matrix

## THE PRODUCT ASSIGNMENT MATRIX

The second matrix developed, is the Product Assignment Matrix, crossing the project Product Work Breakdown Structure with the Process Assignment Matrix. The project PWBS shows, for each specific ship under construction, all interim products that must be done for this ship. Crossing this PWBS, for each one of the products, with the Process Matrix, it is possible to determine:

- What Products will be made,
- What Process will be applicable,

- What Production Unit will be in charge, and
- How much will it cost.

This matrix answers the four basic questions raised

- What?,
- How?,
- Who?, and
- How much?.

An example of this matrix is shown in Figure 4. From this matrix it is possible to define all the control points, as well as to determine all the work packages.

## WORK PACKAGE

The Work Package (WP) is defined as the amount of work of a process to be done by a production unit to obtain a product. That means that a finished product is the sum of different work packages, each work package belonging to a specific process and a prediction unit

Using the NO assignment matrices previously developed, it is possible to define the work packages for each product taking into account the following basic rules:

- Each WP only belongs to a Product
- Each WP only belongs to a specific process,
- Each WP contains a predefined work contents and its corresponding budget
- Each WP must be scheduled,
- Each WP only belongs to a specific Production Unit and must have only one person in charge,
- The size and duration of each WP only depends on the characteristics of the work involved and the conveniences for its control.

Figure 5 shows a typical definition of work packages for a product. Also Figure 6 shows the code used in the test shipyard to describe each WP.

## WORK ORDER

A Work Order (WO) is the interface of the System with the shop. A WO contains the technical description and the time frame for specific task of a certain process, to be performed by a production unit.

A work order is the lowest level control element used in this Production Control System and is the basic element in calculating performance and conducting the production process.

Some important characteristics to be considered when defining work orders are listed below.

A WO is a logical work unit to be executed by a production unit in a practical and reliable manner.

A WO must have a logical start and termination, because it is the basic measure for the progress of the project. When the order is completed there should not be any doubt as to the work accomplished. For this reason, the WO must be defined in utmost detail with reference to the work content and extent, including all corresponding technical information as well as special instructions, material list, pallet list etc.

A WO must have a short duration normally no more than two weeks and a small work content, not more usually than 200 man-hours.

A WO must not be stopped when it has been started. A WO must be done in the exact way that has been planned. If necessary changes must be made, it is

better to cancel the WO and produce a modified new one.

Precision in defining work orders, as well as accuracy in capturing results is the key for a reliable system, and a reliable estimation of final results.

This production control system has defined the following WO types.

- Normal or typical WO, belongs to an unique WP. It is a part of the WP, with a clear definition of the tasks it includes, so that its completion is easily checked. All the tasks in the WO belong to the same process than the WP. This type of WOs represent the majority of edited Work orders.
- Distributed is one WO which belongs to two or more WPs, always made by the same production unit. Its use is restricted to WPs With Small Work Contents whose individual control is difficult
- Service, is one WO corresponding to support works. The hours charged to these WOs are distributed among all the WOs being in execution during their duration period

Normal and distributed WOs may be subcontracted, and the program contains a specific module to deal with this situation.

Figure 7 shows the form used to define and edit WOs in the test shipyard

There are three important criteria applied to the WO definition.

- There should be, as a minimum, one Work Order for each Work Package.
- The sum of WO budgets for each WP should be equal to the WP budget including those distributed WOs dated to the WP.
- The sum of WO work contents for WP should also be equal to the WP work content, including the distributed WOs related to the WP. The schedule of a WO must also be coherent with the schedule of the WP (WPs, in case it is distributed) in which it is derived

In summary, the WO represents an unmistakable work unit which must be performed without disturbances, and under the supervision of a unique responsible person. As the WO has an identified work content, it must have a fixed budget and an integrated schedule.

## COST CONTROL ACCOUNTS

Cost Control Accounts (CCA) represent the visible expression of the Control Points, and allows the management of the different project parts by the way that the Project has been divided

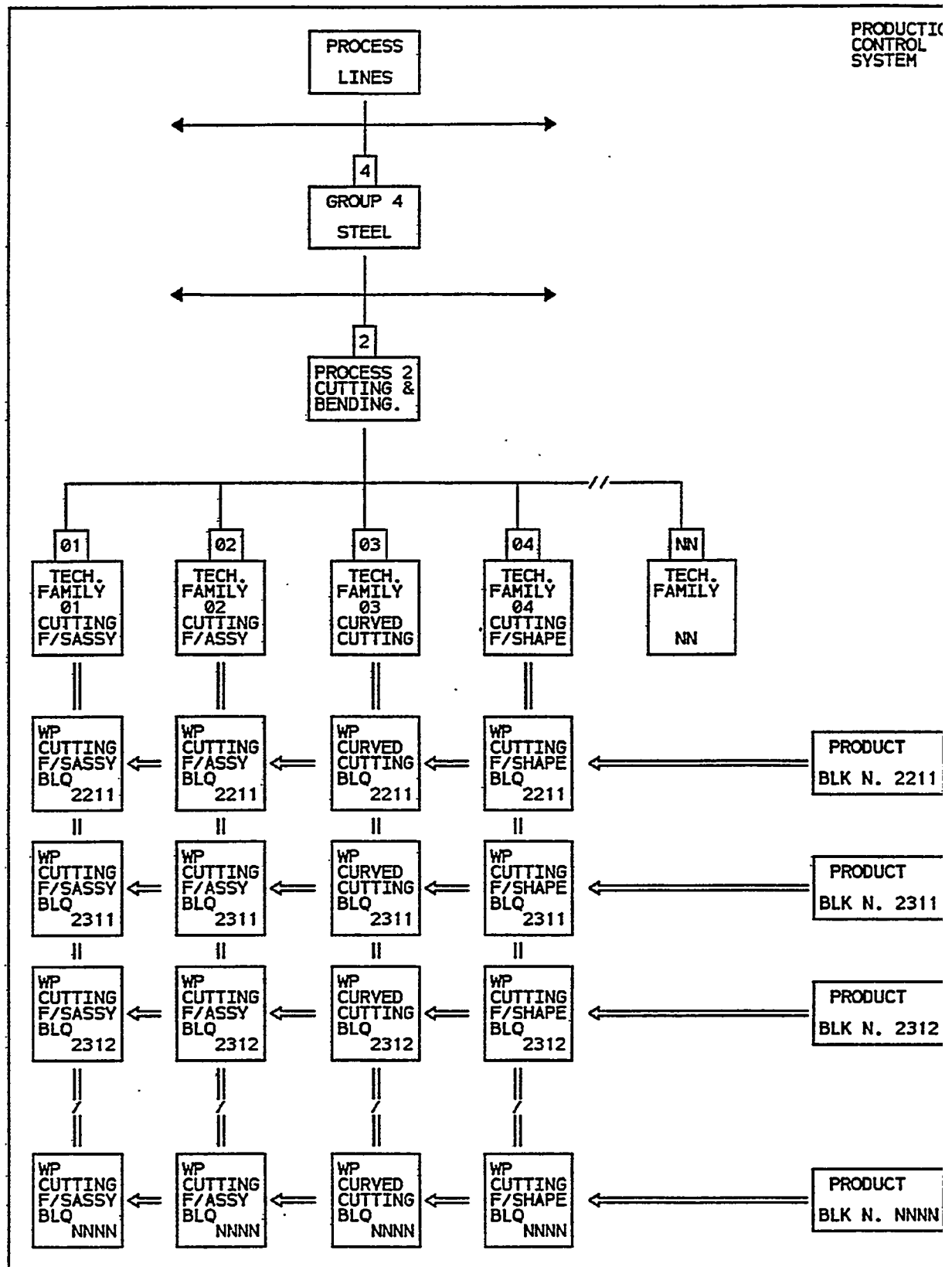


Figure 5. A sample of Work Package definition

## ASTILLEROS ESPAÑOLES S.A.

PRODUCTION  
CONTROL  
SYSTEM

### WORK PACKAGE

PACKAGE n°	333
GROUP	1
PROCESS	1
TECH. FAM.	22
PRODUCT	88888888
OBS-FASE	4444
OBS-UUPP	4444

BUDGET  
 TOTAL BUDGET..... Hrs

SHIP n° \_\_\_\_\_

W.PACKAGE. \_\_\_\_\_

↑  
↑  
↑  
↑  
↑  
↑  
↑  
↑  
↑  
↑

UUPP  
 FASE  
 PRODUCT  
 TECH. FAMILY  
 PROCESS  
 GROUP  
 W.P Number

WORK DEFINITION	UOH <sub>1</sub>	UOH <sub>2</sub>	UOH <sub>3</sub>	UOH <sub>4</sub>	UOH <sub>5</sub>	UOH <sub>6</sub>	UOH <sub>7</sub>	UOH <sub>8</sub>	UOH <sub>9</sub>	UOH <sub>10</sub>	UOH <sub>11</sub>	UOH <sub>12</sub>
UNIT												
CODE												
QUANTITY												
PARAMETER												
TOTAL												

SHORT DESCRIPTION

DETAILED DESCRIPTION

**WORK PACKAGE SCHEDULE.**  
 START.                    \_ / \_ / \_  
 FINISH .                    \_ / \_ / \_

MADE BY:  
 DATE:  
 APPROVED BY:  
 DATE:  
 CHANGED BY:  
 DATE:  
 APPROVED BY:  
 BAR n°

**BUDGET DISTRIBUTION METHOD.**  
 1.- LINEAL  
 2.- FIX PERIODS.(% BUDGET @ 50% PERIOD)  
 3.- SPECIFIC BUDGET CURVE

PER	FROM	TO	QUANTITY
1	— / — / —	— / — / —	
2	— / — / —	— / — / —	
3	— / — / —	— / — / —	
4	— / — / —	— / — / —	
5	— / — / —	— / — / —	
6	— / — / —	— / — / —	
7	— / — / —	— / — / —	
8	— / — / —	— / — / —	
9	— / — / —	— / — / —	
10	— / — / —	— / — / —	

Figure 6. A sample form used for Work Package definition

ASTILLEROS ESPAÑOLES S.A.		PRODUCTION CONTROL SYSTEM																																				
<b>WORK ORDER</b>																																						
<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">WORK PACKAGE NUMBER..... 333</div> <div style="border: 1px solid black; padding: 2px;">WORK ORDER NUMBER..... 666666</div>	<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">SHIP Number..... 333</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">GROUP..... 1</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">PROCESS..... 1</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">FAMILY..... 22</div> <div style="border: 1px solid black; padding: 2px;">PRODUCT.....4444</div>	<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">FASE..... 4444</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">UOPP..... 4444</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">BLOCK.....4444</div> <div style="border: 1px solid black; padding: 2px;">S/ZONE.....4444</div>																																				
<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">WORK ORDER TOTAL BUDGET..                      Hrs</div> <div style="border: 1px solid black; padding: 2px;">WORK ORDER TYPE: NORMAL/DISTRIBUTED</div>																																						
<div style="border: 1px solid black; padding: 2px; height: 30px;">SHORT DESCRIPTION.</div>																																						
<div style="border: 1px solid black; padding: 2px; height: 150px;">DETAILED DESCRIPTION.</div>																																						
<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">WORK ORDER SCHEDULE</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">START.                      _ / _ / _</div> <div style="border: 1px solid black; padding: 2px;">FINISH.                      _ / _ / _</div>		<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">WORK ORDER ACTUAL DATES</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">ACTUAL START              _ / _ / _</div> <div style="border: 1px solid black; padding: 2px;">ACTUAL FINISH              _ / _ / _</div>																																				
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Figure 7. A sample form for Work Order definition

A CCA inside the system is defined by a certain selection of Work Packages, and different selections of WPs produce different types of CCAs. It is possible to sum the WPs belonging to a product, and have a CCA

specific product as for a process or for a production unit. The codification system for the WP, which includes characterization blocks for product, processor production unit permits all the possibilities, and renders this system flexible and reliable.

## FUNCTIONAL STRUCTURE OF THE PROGRAM

The program has been developed with modular organization concepts. In this way it has been possible to use some modules while others were in the development stage. In the paragraphs that follow modules are described in the generic order they are used when controlling a new construction project.

### Project Definition Module

The objective of this module is to allow a user to define a project. This definition includes the specification of the work to be performed (and of the required manpower), the departments responsible for it and its scheduled time distribution. The final product of this module is a performance measurement baseline, that relates the accumulated manpower to be used with time. This baseline may consider the whole project or maybe built by product process, organization or any combination of them.

In the terms described so far, it is possible to state that this module allows a user to specify for a project the Interim Products of the Work Breakdown Structure, the Process Breakdown Structure, the Organizational Breakdown Structure, the Process Assignment Matrix and finally, the Product Assignment Matrix.

While the project progresses, a more detailed knowledge is obtained about the work that is necessary for each interim product. Typically, three situations are considered for the project. The first one has available the information that is generally known at the time a contract takes effect. The second situation considers the information at the time the building strategy is fixed and the third one has available all the information contained in the detailed design.

The specification of a project may be done at any of the situations referred to. The later in a project life the more detailed the information will be. Then it is possible to build Work, Process and Organizational Breakdown Structures, and Process and Product Assignment Matrixes for each of these situations, although the level of detail will vary.

The monitoring of performance is carried out at the most detailed level, in order to obtain maximum accuracy. However, it has been considered useful to include in the module the possibility of specifying the project at the initial levels, with two objectives

To distribute the budget entirely and have a global vision of a project at any time, although with a smaller level of detail, and

- To obtain performance estimates referring to the processes and units of measurements defined for the initial levels, once the final results are known. These performance ratios are used for estimates of future ships, thus feeding the estimation cycle with actual results.

The result of this module is a database containing the above mentioned structures plus the work packages for each level of specification selected. The databases are related in such a way that, for a given product, it is always possible to compare the work packages obtained at different levels.

The product process and organization structures are defined as hierarchical structures. There is a set of program utilities for the management of this kind of structures, allowing users to create or modify them with the minimum restrictions to assure their integrity.

Another set of utilities is provided for the management of the work packages. This allows users to create, modify, list, graph, etc, the work packages of every database. Also it is possible to obtain numerical and graphical expressions of any performance baseline by process, product or organization.

Another utility of the module allows the handling of the management reserve. Exchanges between work packages and management reserve are possible in both ways, with all the necessary cautions to maintain the integrity of the system. It is possible to obtain detailed reports of the evolution of the management reserve, as well as of records showing the nature of all changes carried out.

The module allows the connection with the planning and schedule systems in some of the shipyards. However, a high degree of manual handling of work packages is still needed, for at present there is not a unified approach to planning in all the new construction shipyards using the system.

### Work Order Issuing Module

Work orders are the interface of the system to the shops. The production system of the shipyard does not need acknowledge of the Product Assignment Matrix or of any of the structures used by the system. All work packages are broken down (or grouped) into work orders, that are issued to the shops approximately three weeks in advance of their scheduled beginning. It is up to the shops to prepare a detailed programming of their work, with the orders they have received.

The normal WO module makes sure that each WO complies with the restrictions on the quantity of work imposed by the work package it is related to. For distributed work that belong to several work packages, the proportion of effort assigned to each work package is recorded, with a check on the suitability of the assigned workload.

The utilities included in the module allow easy handling of new or existing orders, including creation modifica-

tion, issue, opening and closure of work orders. The module offers users the possibility of customizing reports on work orders issued, or on work orders in various states of readiness, such as approved but not issued, pending approval, in process, due finished or closed. It is possible to limit the scope of reports in the customary way to any combination of the product process and structure organizations. Furthermore it is possible to obtain reports about the orders issued for each work package, thus allowing the controller to be aware at anytime of the degree of fulfillment of a given work package.

#### Subcontracting Module

The system has a specific treatment for subcontracted work orders. Normal and distributed work orders may be assigned to subcontractors. They are included in the system in every respect, although reports concerning these orders are kept separate from orders carried out in the same shipyard. It is possible to obtain a combined report on completed work and, once subcontracted orders are finished to compare their costs with similar orders not subcontracted. The definition of the building strategy includes an estimate of the products or work packages that will be subcontracted during the project but subcontracting is also decided on the fly' to solve production problems that may arise. The system allows users to define work orders as subcontracted at any time (until actual hours are charged to the work order).

The issuing of subcontracted orders is similar to that of in-house orders, except that it is divided into several stages, due to the intervention of the purchasing department of the shipyard. The initial issue of a WO, with all technical details, is returned from the purchasing department with information regarding the external shop that has received the order, scheduled dates and contract cost. When the WO is completed and delivered back to the yard its status becomes "closed" and new information about delivery date, inspection or transportation costs, etc, is added.

Subcontracted work orders may be carried out in the external suppliers' shops or within the yard. In the former case, no hours are charged for shipyard services, such as movement or WO preparation, while in the latter case service hours are recorded and included in the cost of the WO.

Reports similar to those for in-house orders are available, plus some others regarding subcontractors by Processes or delivery schedule.

#### System Update Module

The main program of the module is a batch program that is run at the end of each accounting period. Its aim is

to keep the system abreast of actual costs incurred for tasks currently being executed. Actual labor cost retrieved from the standard personnel database of Shipyard. Daily information about the hours assigned every work order by every worker is stored in this database.

The system does not require a fixed length for accounting periods. Nonetheless it is customary for the shipyard to update the system weekly. Some shipyards make changes to the accounting periods in order to have information about complete months.

The main functions carried out by the update module are listed below.

- Integrity checking of the system that maybe carried out anytime interactively, allows users to analyze the files retrieved from the personnel database to detect inconsistencies between these files and the system database
- Updating of the WO historical database with actual charged hours information for the latest accounting period;
- Apportionment of service hours to Work Orders currently being executed.
- Calculation of main values for each VIP during accounting period: Budgeted Cost of Work Schedule (BCWS), Budgeted cost of work Performed (BCWP), Actual Cost of work performed (ACWP) and Secondary Costs;
- Historical WP database update,
- Update of Cost performance Index (CPI) Value Estimates at Completion (EAC) for each WP in historical WP database,
- Update of historical databases for elements of the Project Work Breakdown Structure (PWBS), PBS and OBS hierarchies, and
- Revision and update of all historical databases, into account the subcontracting occurred during last accounting period.

The time taken to run the system update function depends largely on the amount of subcontracting during latest accounting period, because this variable requires revision of historical databases from the beginning of project. Once this revision is carried out the values of WP and for any given time reflect the latest known about the amount of work that has been subcontracted. Average updating time in an accounting period with subcontracting and about 1,500 work packages, 6,000 orders, with about 400 of them active is about 1/2 day. This timing has been obtained for the Production Control System running on a standard PC 486/66. Once the updating is over, reports are immediately available to anyone over the network. It is normal to have printed reports reflecting changes that have occurred up to 24 hours after updating.



## ASTILLEROS ESPAÑOLES S.A.

**FACTORIA DE PUERTO REAL**

SHIP #:

REPORT BY PBS  REPORT TYPE:

GROUP:

PROCESS:

TECH. FAMILY	BCWS	BCWP	SV	ACWP	CV	BAC	EAC	CPI	TCPI
01									
02									
03									
04									
NN									
TOTAL									

**PRODUCTION CONTROL SYSTEM**

REPORT DATE: \_\_/\_\_/\_\_

DATA AS PER: \_\_/\_\_/\_\_

---

03

04

NN

TOTAL

TECH. FAMILY	BCWS	BCWP	SV	ACWP	CV	BAC	EAC	CPI	TCPI
01									
02									
03									
04									
NN									
TOTAL									

PROCESS:

TECH. FAMILY	BCWS	BCWP	SV	ACWP	CV	BAC	EAC	CPI	TCPI
01									
02									
03									
04									
NN									
TOTAL									

TOTAL SELECTION

	BCWS	BCWP	SV	ACWP	CV	BAC	EAC	CPI	TCPI

BCWS. BUDGET COST WORK SCHEDULED  
 BCWP. BUDGET COST WORK PERFORMED  
 SV. SCHEDULE VARIANCE  
 ACWP. ACTUAL COST WORK PERFORMED  
 CV. COST VARIANCE  
 BAC. BUDGET AT COMPLETE  
 EAC. ESTIMATE AT COMPLETION  
 CPI. COST PERFORMANCE INDEX  
 TCPI. TO COMPLETE PERFORMANCE INDEX

Figure 8. A sample of one accounting period report by process

### Reporting Module

The reporting module can produce simple and powerful reports that describe the state of a project at any level of detail. The operation of the module has been designed as user friendly as possible, for this is the only module used by most of the shops and production managers. The reports are offered in numerical and graphical form whenever possible.

Presently three types of reports are offered to users.

**Cost and schedule reports. (Figures 8 and 9).**

These reports allow a user a quick vision of the variables usual to CSC systems, as shown in the figures.

These values are shown for the last accounting period or for the last  $n$  periods, where  $n$  may be chosen by the user, with a maximum of 6 for reasons of space in the report (all of them are presented in A4 format). It is possible to obtain similar reports between two arbitrarily selected updating dates, grouping all the accounting periods between them. This utility allows users to analyze performance during a given period in a shop, for any desired process or interim product.

## ASTILLEROS ESPAÑOLES S.A.

FACTORIA DE PUERTO REAL

SHIP #:

REPORT BY OBS:

REPORT TYPE:

PHASE:

DATA AS PER:

### PRODUCTION CONTROL SYSTEM

REPORT DATE: / /

DATA AS PER: / /

TOTAL											
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PROD. UNIT:			BCWS	BCWS	SV	ACWP	CV	BAC	EAC	CPI	TCPI
GR.	PROC.	T.FAM.									
TOTAL											

PROD. UNIT:			BCWS	BCWS	SV	ACWP	CV	BAC	EAC	CPI	TCPI
GR.	PROC.	T.FAM.									
TOTAL											

BCWS	BCWS	SV	ACWP	CV	BAC	EAC	CPI	TCPI
TOTAL SELECTION								

BCWS - BUDGET COST WORK SCHEDULED  
 BCWP - BUDGET COST WORK PERFORMED  
 SV - SCHEDULE VARIANCE  
 ACWP - ACTUAL COST WORK PERFORMED  
 CV - COST VARIANCE  
 BAC - BUDGET AT COMPLETE  
 EAC - ESTIMATE AT COMPLETION  
 CPI - COST PERFORMANCE INDEX  
 TCPI - TO COMPLETE PERFORMANCE INDEX

Figure 9. A sample of one accounting period report by organization

There is a degree of flexibility allowed to a user for customizing the report regarding the selection of the work packages whose values make up the report. The user is requested to decide the scope of the report using any combination of the elements of the Product Work Breakdown Structure, the Process Breakdown Structure and the Organizational Breakdown Structure. The selection process is organized using the hierarchical nature of these structures, and has been shown to be quickly comprehended by users with very little or no computer experience. It is very easy to select the information regarding the whole project, a shop, all activities of a production group, some processes carried out by a specified production group, a whole process, a product, or a combination of products of a certain level.

Graphic reports are offered, in addition to numerical ones, covering the evolution of BCWS, BCWP and ACWP from the beginning of the project. Also the evolution of CPI may be followed in a graph.

All reports are interactively obtained and may be followed on screen or copied on paper. Another property of the information obtained is that it is possible to obtain reports for any given accounting period not only for the current one. This possibility is explained by the exhaustive historical records that are kept for the state of the project on any date since its beginning. The only difference that may be found between the report for a previous accounting period (obtained at the time of that period) and the same report obtained at a later date is that it incorporates all information regarding subcontracting that has been generated after the accounting period ended.

**Reports** may be obtained for in-house work, for sub-contracted work or for a limited combination of both. Also, in the case of in-house work, it may be desired to incorporate the service hours to the Budgeted Cost and to the Actual Cost of Work Performed, or to obtain a report showing only the direct costs, without services.

#### Productivity Reports.

It is possible to obtain at any time during a project or at its@ an estimate of the technical productivity rates that have been obtained during the project Productivities are derived statistically using as observations the actual man-hours spent in every finished WO included in the desired selection by Product or Organization.

The productivity is obtained for a single processor a range of processes, and its scope is determined by a selection process very similar to that outlined for the previous reports, but containing only the PBS and the OBS. For instance, it is easy to obtain the rates for welding thin or thick pipes (a uniquely determined process with two units of measurement), when this process is carried out by a specific production Unit or selecting some of the products that contain the process it is desired to analyze.

As the system keeps complete historical records of the evolution of the project, it is possible to ask for reports about the productivity rates at the end of any accounting period, not necessarily the last one.

Once the project is finished, the same module is used to compute statistical estimates of the productivity rates in terms of the parameters used in the first or second level definition of a project Those values may be used in figure estimation of workload.

#### Report of the Work Carried Out in a Period of Time

A functionality has been developed to obtain reports showing the hours charged during a certain period of time, selected by the user. The listings show how much effort has been dedicated during the selected period to a certain range of tasks. The information offered include the following

WOs that received any charges during the period scheduled and actual dates for these orders, man-hours charged during the period and accumulated status at the beginning and end of the period and cost and schedule variance

- Work packages acted upon during the period scheduled and actual dates for these packages, man-hours charged during the period and accumulated status at the beginning and end of the period percentage completed at beginning and end of period cost and schedule variance, and

Similar information is provided for products that have received charges during the period.

The range of information may be selected by a similar process to that described for previous reports.

#### Auxiliary Modules

There are a number of modules that are necessary for the operation of the system but add little from the theoretical point of view. Some of these are

- Utility for backing-up and restoring information based on those offered by the databases,
- Utility for initiating a database for a new project with partial copy from a previous project;
- Security system, based on personal and departmental keys for all functions of the system and an On-line Help system.

The simple enumeration of these systems makes clear their function.

#### SYSTEM IMPLEMENTATION PROCESS

At the beginning of 1993, the Technological Development Direction of the corporation was assigned the task of defining the theoretical basis of developing and implementing a production Control System. It was a condition of the system to agree entirely with the new concepts of construction by zones and stages and group technology, recently integrated into the production system of the shipyards owned by the corporation

The main aim of the assignment was to improve shipbuilding management within a larger program of increasing the shipyards competitiveness.

From January to June, 1993, all the theoretical bases of the System were developed as well as the basic decomposition structures. The work was jointly carried out by the Technological Development Direction and production teams from shipyards. One shipyard was chosen as the test facility.

The selected objective was the initial implementation of the system to control the building of a sophisticated 120,000 DWT shuttle tanker and a sister ship that was to follow. For this purpose, it was necessary to redefine the specification of the project according to the System theory, and accommodate all work packages and later work orders according to the same theory. A precondition of the work was to obtain all the information from the shipyard with the minimum disruption of the systems then being used at the time. The objective was met adequately.

The analysis and programming of the computer program that was meant as the system support was began simultaneously. A decision was made to produce the first implementation of the computer program on a PC. The idea was to use an inexpensive device, well known in the shipyards and user friendly, which could be easily extended through a local network. The program was developed in a

modular form as has been described. Milestones in its development and implementation were as shown in Table II

<b>Specification of the project and baseline analysis</b>	
Beginning	February, 1993
1st Operational Version	March, 1993
2nd Operational Version	June, 1993
<b>Cost and Variance Reporting</b>	
Beginning	May, 1993
1st Operational Version	September, 1993
2nd Operational Version	December, 1993
<b>Version 1.0:</b>	
1st Operational Version	March, 1994
2nd Operational Version	July, 1994
<b>Operational tests:</b>	
Initial tests	May - September, 1993
Pilot application	September, 1993-July, 1994

Table II: Implementation stages of the system

From March 1994, the system has been regularly applied and it has already been used for three new buildings, two shuttle tankers and a VLCC.

The system results are considered as official for control and personnel purposes in one of the shipyards since the beginning of September 1994 for steel processes and, from December 1994, for outfitting processes as well.

The conceptual basis and initial results of the system have been discussed with the managers from other corporate shipyards and the implementation schedule for these shipyards has started in September, 1994.

The productivity module, containing estimation for future construction is in the test period and will come into normal use by November 1994.

### Implementation

Implementation in the shipyard and real life application have not been an easy task. Even with the full cooperation of the production team, it was necessary to overcome a number of difficulties, such as noted below

#### Product Identification and Definition.

The factory already used a product catalogue in its production system. However, it was necessary to carry out a further *clarification* of existing products. The aim was to obtain suitable products for production control purposes, not too small for control operation, not too big and complex

for a meaningful contents definition. This is a continuing effort that is being improved from ship to ship.

#### Process Identification.

A similar task was the identification and normalization of processes, according to Group Technology theory.

#### Organization Definition.

Initially the existing organizational structure of the factory was left unchanged but experience in the system is providing clues for its improvement

#### Work documentation.

The previous work documentation system has had to be adapted to the requirements for the new Work orders. It is necessary to balance the need for more detailed documentation of the work orders to the shops with the increasing manpower required to prepare them.

#### Personnel Instruction.

Another worthy task has been to persuade all foremen and workers of the importance of a correct assignment. Time spent hours to the actual work order. The reliability of information is the cornerstone of the whole system of real time monitoring.

This implementation process is being enhanced by the production of a System Manual. It contains the operational aspects of the system, as well as its influence over Production Organization. This manual will complement the program's User Manual, and on-line help.

### CONCLUSIONS AND PLANNED DEVELOPMENTS

According to expedience, the operation of the system, briefly described in this paper has two main advantages:

Swift and ad-hoc information thus improving managers' decision making and corrective actions, based on accurate and timely information.  
Superior capacity for the analysis of efficiency in the various shops, processes and products.

This situation increases managers' capabilities to promote improvements in productivity and more accurate estimates for future projects. It also shows the System helps foresee situations and problems, increasing the competence of the shipyards.

A number of improvements and extensions are planned for the described Production Control System;

- Improved connection to Planning Systems.
- Full development and use of the Product concept Integration of materials in the Control System.
- Development of an object repository for connection with CAD systems and Production Engineering.
- Development of a graphical deviation analysis module.
- Development of a module for the simulation of production decisions.

The Production Control System is meant to be a useful element in the planned Computer Integrated Manufacturing System envisioned as necessary to keep yards competitive in the global shipbuilding market

#### ACKNOWLEDGMENTS

The authors would like to show their acknowledgment to Mr John J. Dougherty for work and continuous advice during the time of the System basic development.

During the preliminary stages of this project, contact Was established With Other advanced Shipyards, especially Saint John Shipbuilding Ltd, which gave us important ideas and suggestions in the way to translate the very sophisticated Cost, Schedule and Control systems to this Production Control Systems more adequate for a commercial shipbuilding program.

Last but not least the authors thank the great efforts of the cooperating production teams in the test shipyard, who have passed along gladly their experience and have suffered all our mistakes.

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